Image Correlation / 4D analysis

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Laboratoire 3SR, Grenoble

2017-05-19 Hercules School on Quantitative Imaging

Pre-introduction

This is a talk about quantitative measurements of displacements (better: kinematics) between images

Not *on* images but *with* or even better *between* images

Introduction

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- These materials deform under stress in complicated ways
- Understanding how will allow safer engineering work
- $\Rightarrow$ Mechanical tests with *in-situ* tomography <video!>

What about quantitative imaging?

- Engineers need to know how stresses σ and strains ϵ are related
- Simple, initially elastic 1D example:

https://www.youtube.com/watch?v=Adhwk1ISH2w

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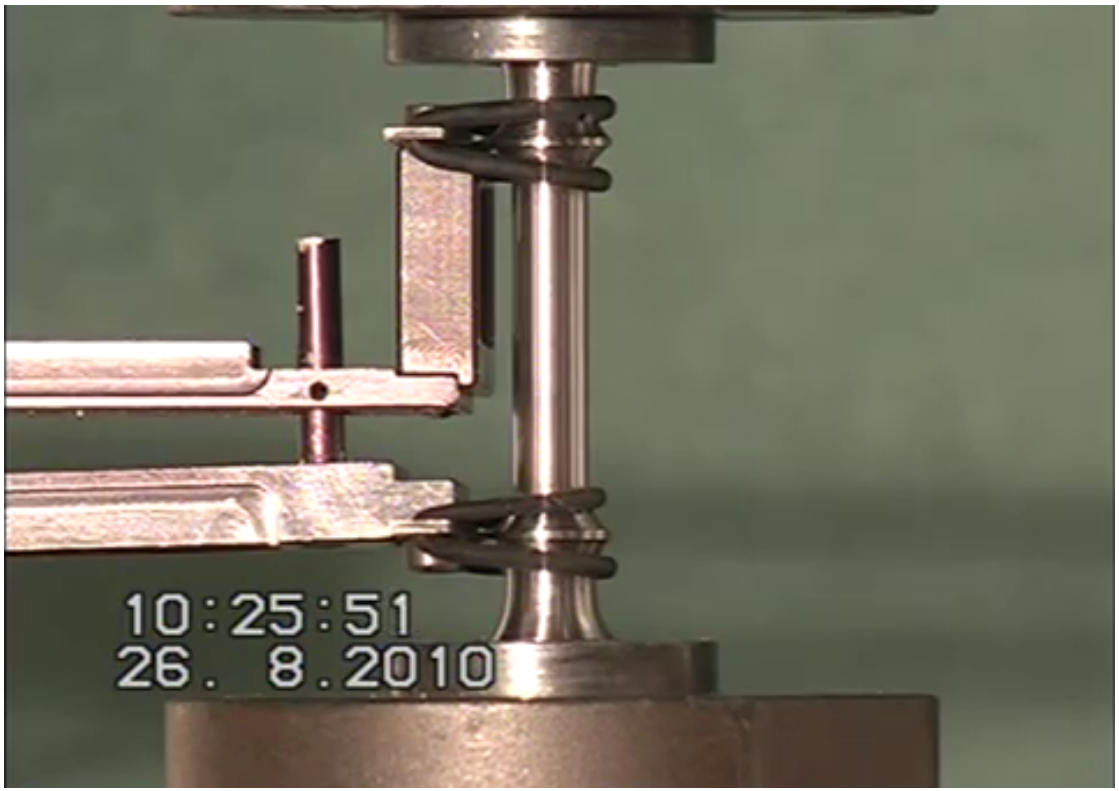

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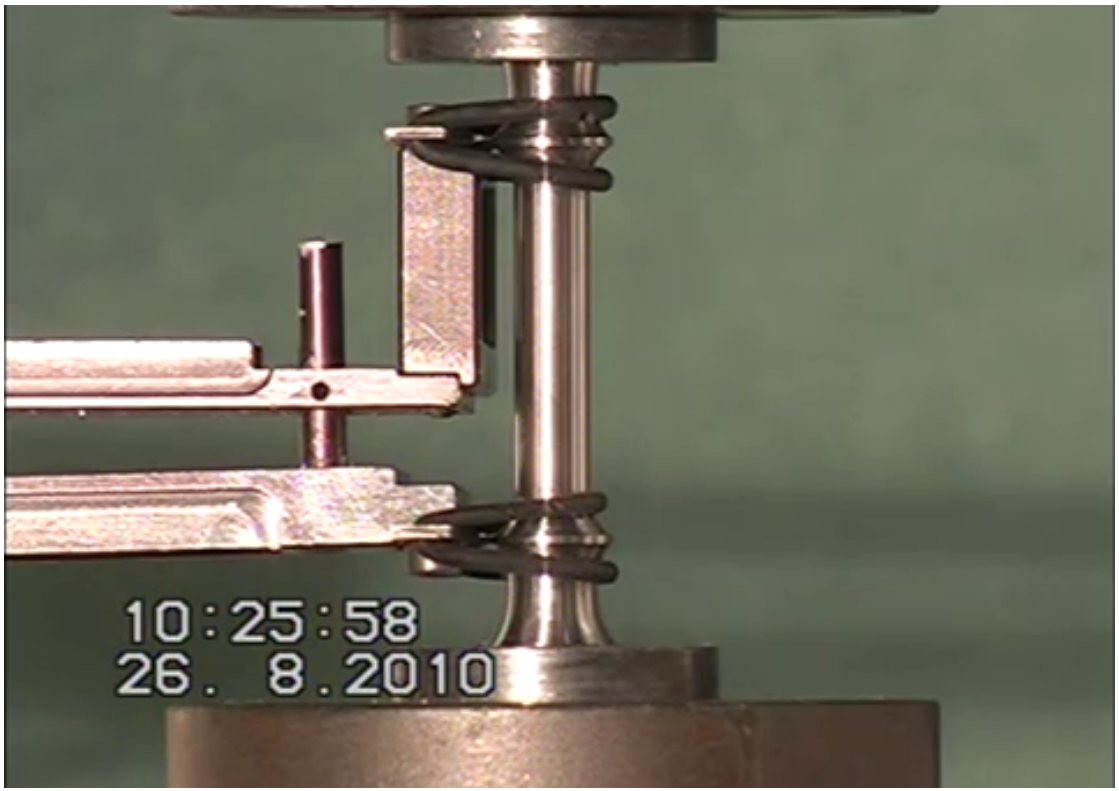

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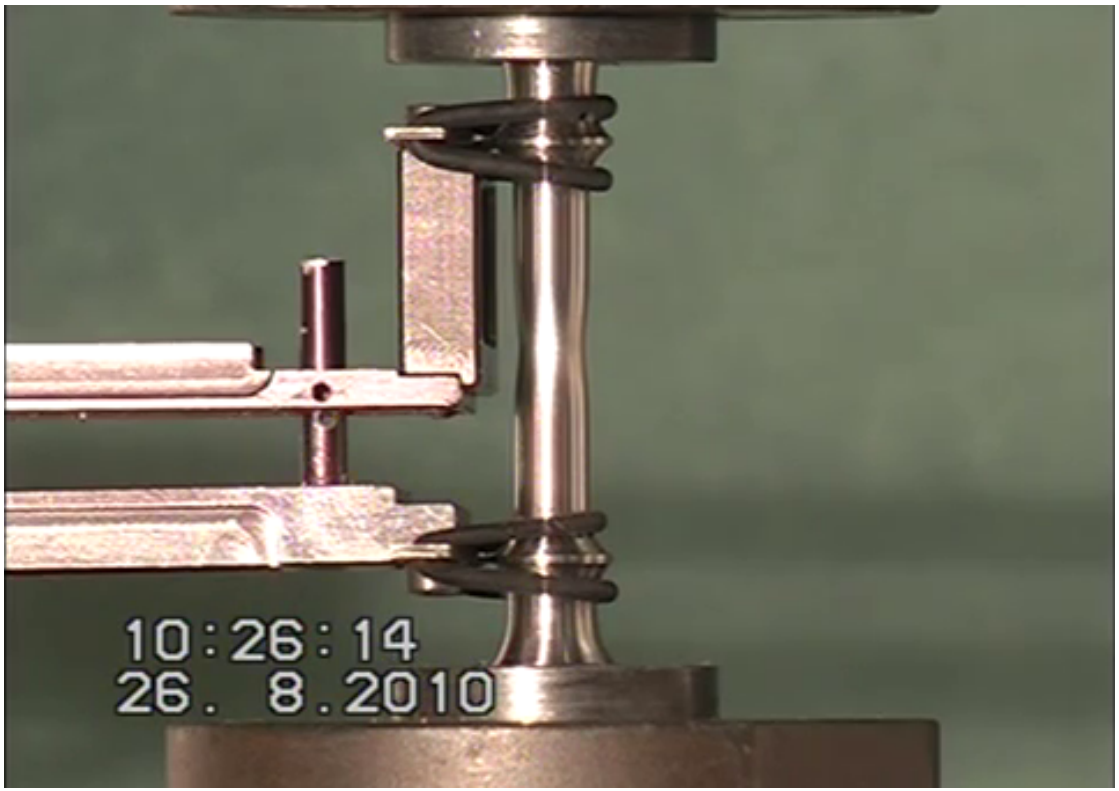

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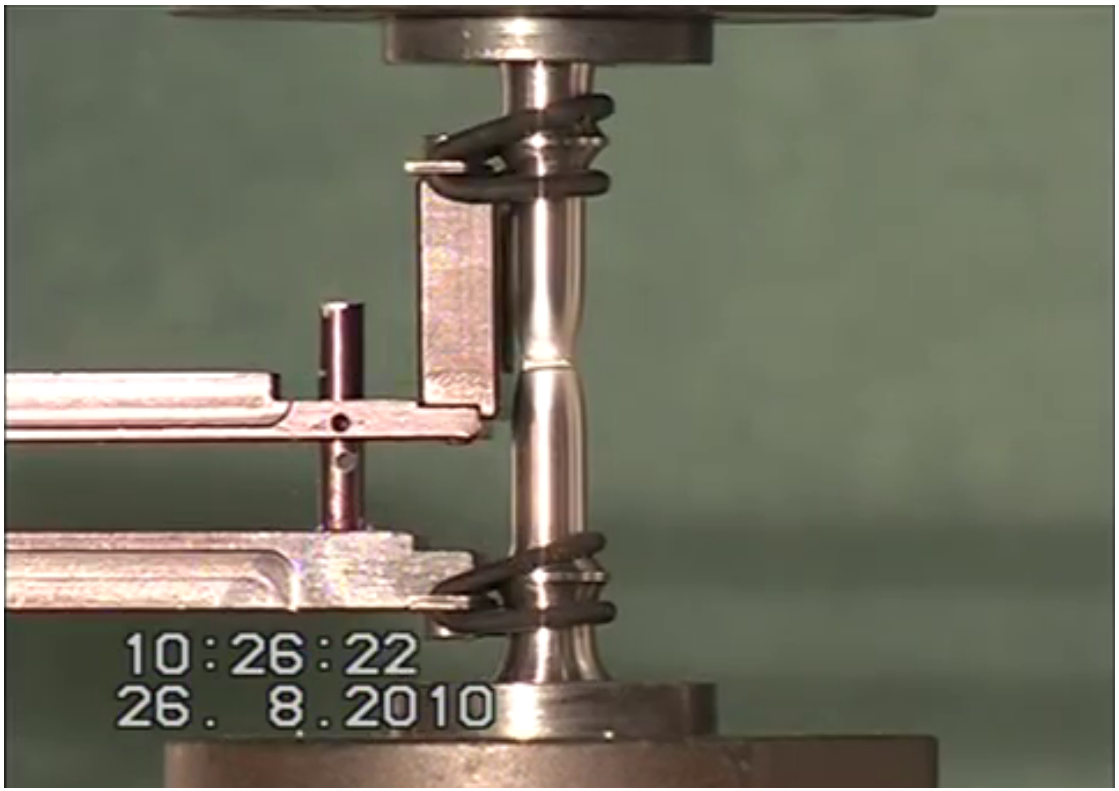

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Back to experiments geomaterials

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Why is this important?

<landslides etc >

Stresses and strains again

Can we measure a field of stress?
Not easily, but: see work of Andy King, Jon Wright, Stephen Hall

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We can more usually have **averaged stress** and **field of strain**

Is it interesting: yes

Let's do it: Measuring deformation

Take two 3D images and map one onto the other.
$f(x) = g(x + u)$

Family of techniques known as:

- Digital Image/Volume Correlation (DIC/DVC)
- Template/Texture Matching
- Image Registration

This is where it gets quantitative.

Let's do it: Measuring deformation

Take two 3D images and map one onto the other.
$f(x, y, z) = g(x + u, y + v, z + w)$

Family of techniques known as:

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This is where it gets quantitative.

Big works and names

- Hutton's book on DIC
- Michel Bornert
- François Hild and Stéphane Roux
- Julien Réthoré
- And many others...

Measuring differences

To measure the quality of a match we need a measure of the quality of the mapping:

1. Normalised Cross-Correlation

$$NCC_{u,v,w} = \frac{\sum_{x,y,z} F(x,y,z)G(x+u,y+v,z+w)}{\sqrt{\sum_{x,y,z} F(x,y,z)^2 \sum_{x,y,z} G(x+u,y+v,z+w)^2}}$$

if F == G; $NCC_{0,0,0} = 1$

2. Sum of the Squared Differences

$$SSQD_{u,v,q} = \sum_{x,y,z} (F(x,y,z) - G(x+u, y+v, z+w))^2$$

if F == G; $SSQD_{0,0,0} = 0$

Different families of techniques

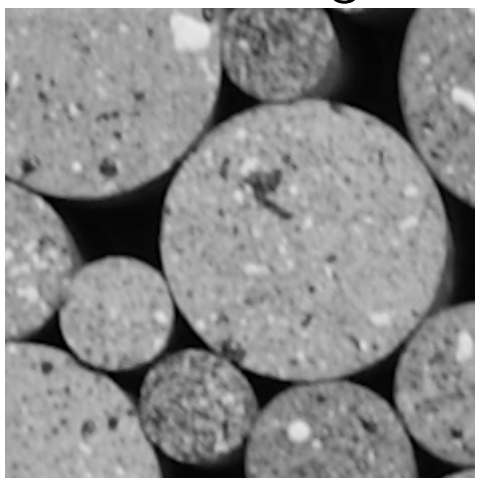
How do we measure a field of displacements?

1. Point-by-point **Local calculation of match**
2. As a field with "continuous" strain **Global calculation of match**

How the pixel search for DIC works... 1D displacement on one "point" – Local!

Correlation Window (Image 1)

Reference Image



Empty			really						empty	
Table						very				

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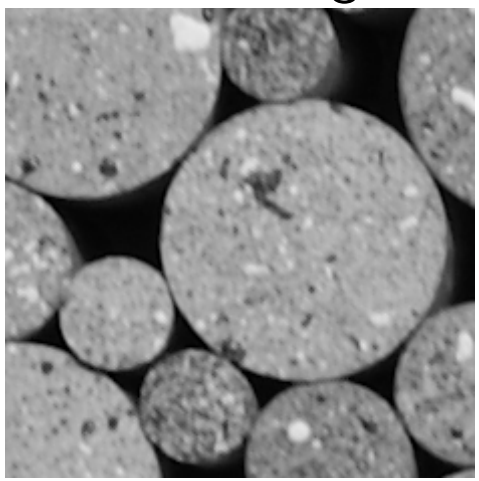
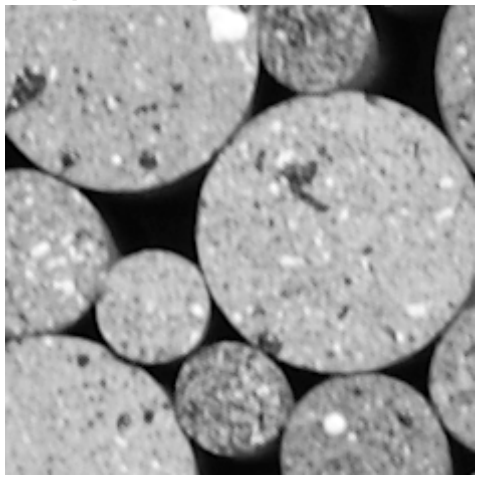


Correlation Window (Image 2)
displacement on table



x disp (px)	0	+10	+15	+17	+18	+19	+20	+21	+22	+23
CC	0.914									

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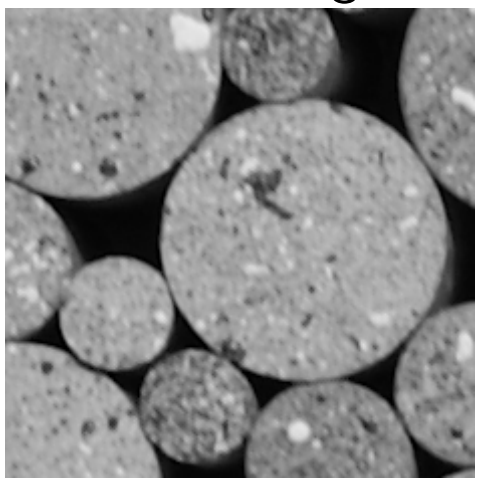

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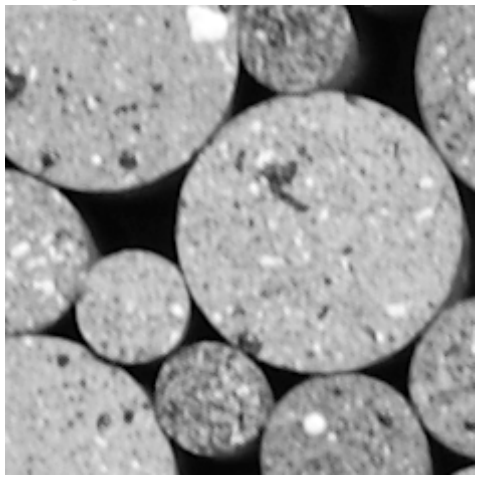

x disp (px)	0	+10	+15	+17	+18	+19	+20	+21	+22	+23
CC	0.914	0.948								

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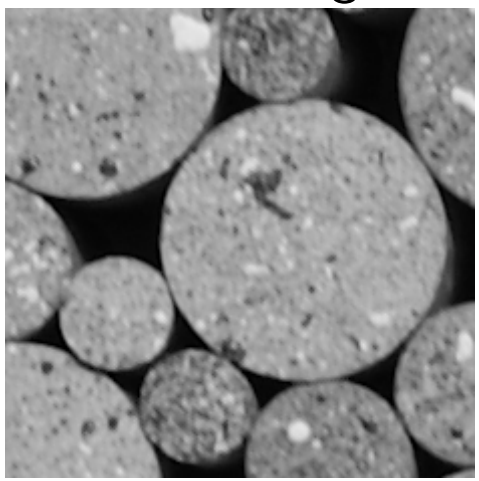

Correlation Window (Image 2)
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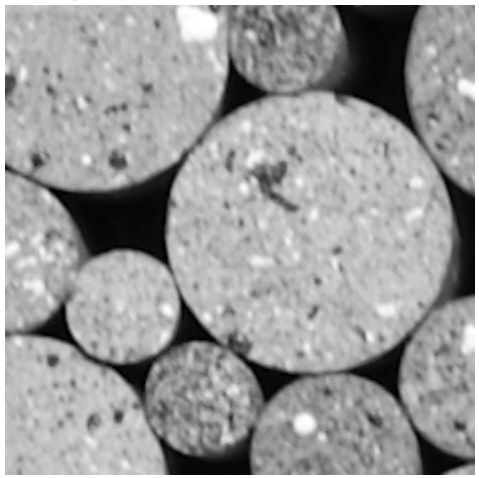

x disp (px)	0	+10	+15	+17	+18	+19	+20	+21	+22	+23
CC	0.914	0.948	0.978							

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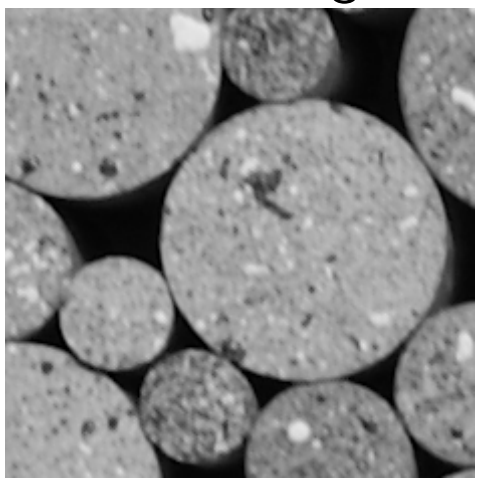

Correlation Window (Image 2)
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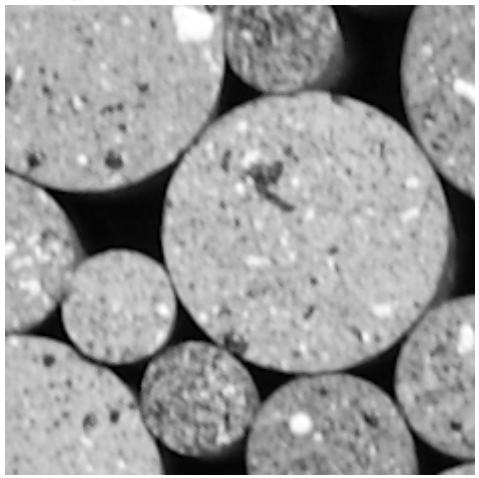

x disp (px)	0	+10	+15	+17	+18	+19	+20	+21	+22	+23
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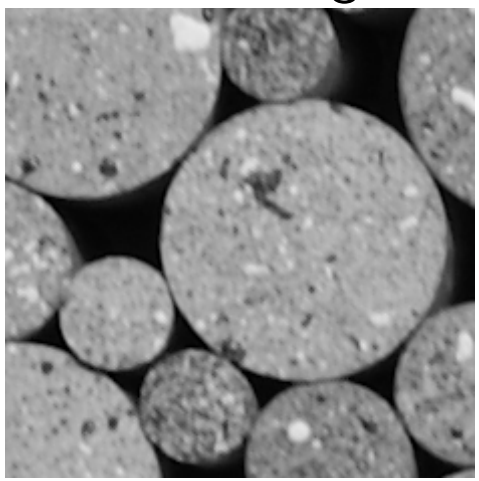

Correlation Window (Image 2)
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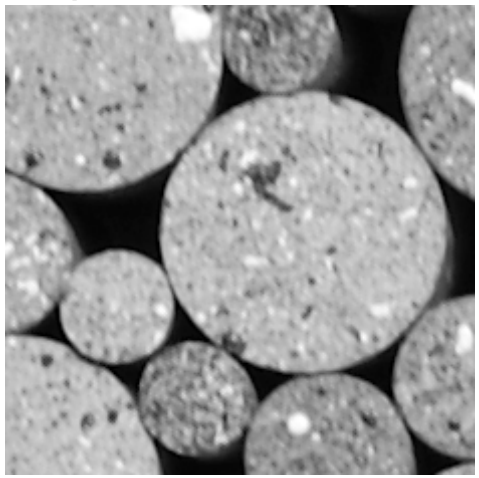

x disp (px)	0	+10	+15	+17	+18	+19	+20	+21	+22	+23
CC	0.914	0.948	0.978	0.984	0.988					

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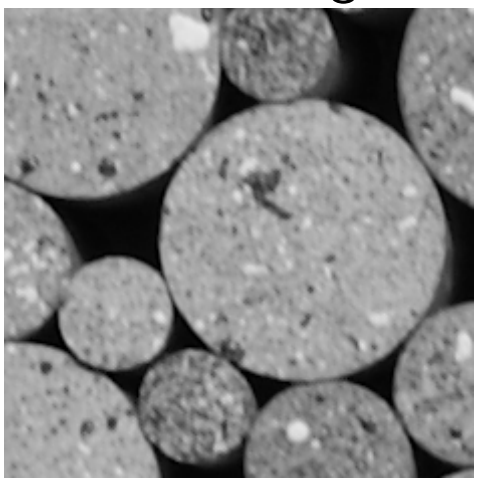

Correlation Window (Image 2)
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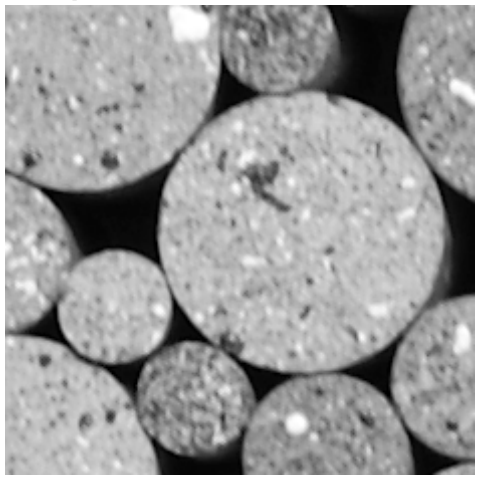

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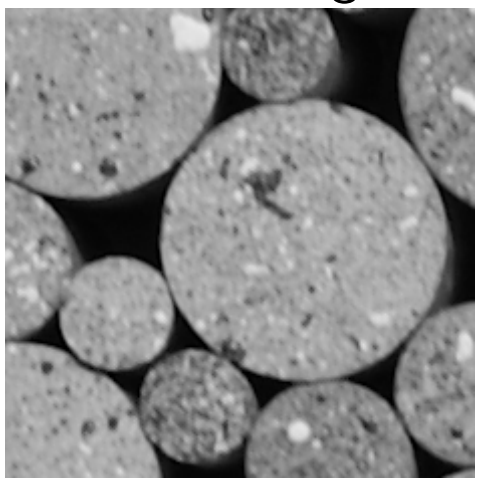

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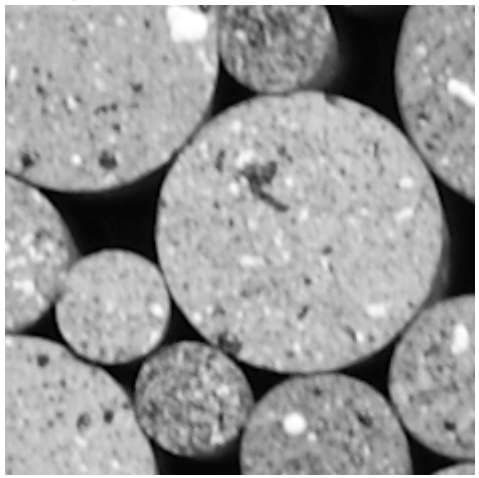

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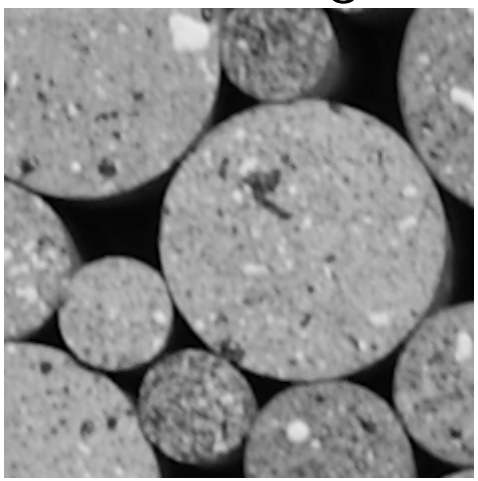

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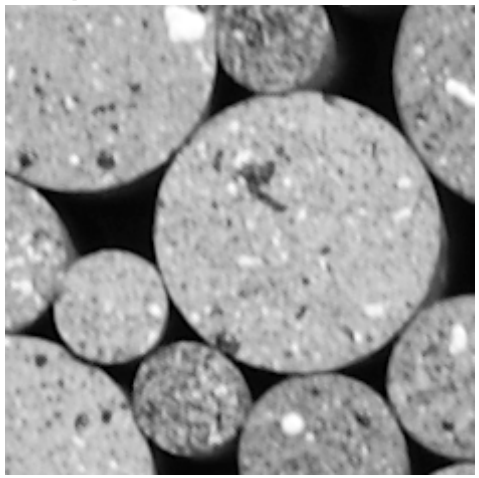

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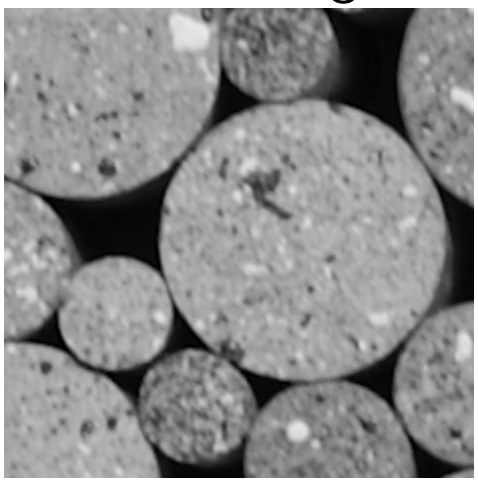

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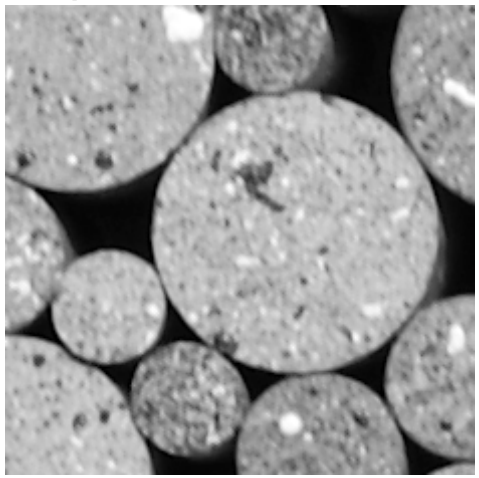

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CC	0.914	0.948	0.978	0.984	0.988	0.987	0.983	0.977	0.970	

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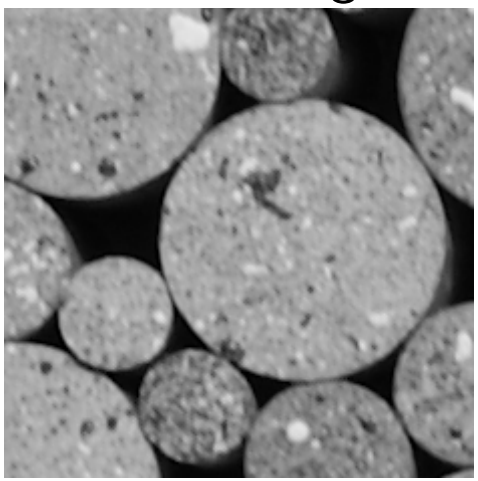

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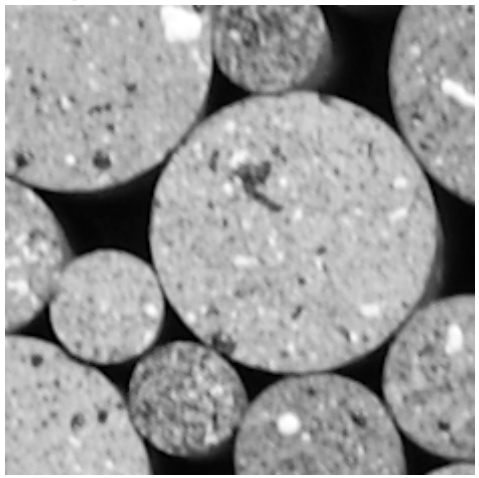


x disp (px)	0	+10	+15	+17	+18	+19	+20	+21	+22	+23
CC	0.914	0.948	0.978	0.984	0.988	0.987	0.983	0.977	0.970	0.964

Results for this measurement node

So...

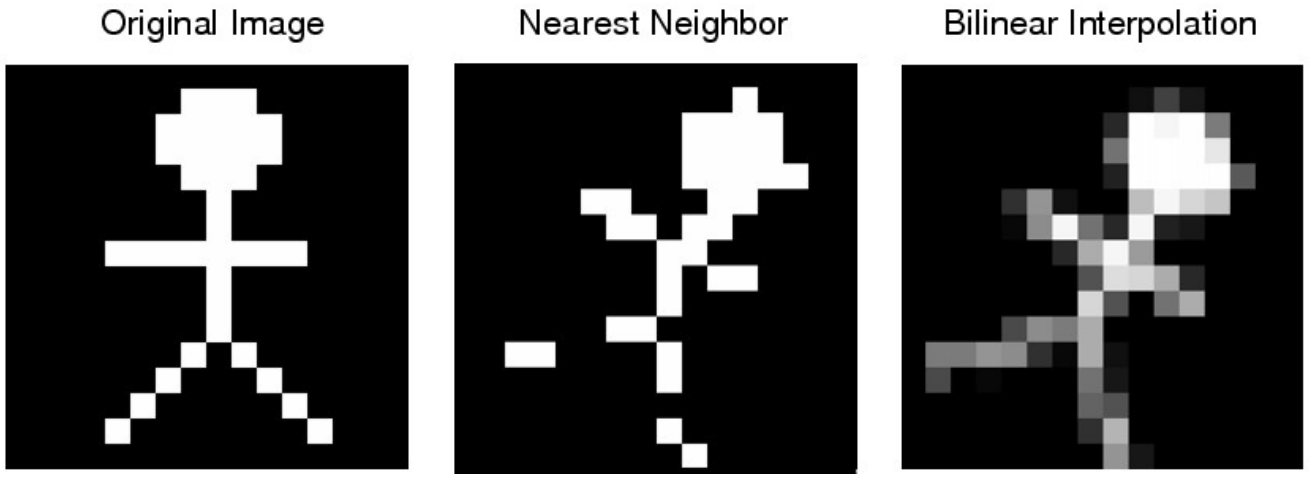
- Scanning in one direction we've found a peak in the CC
- Search range was $x = [0, +23]$
- This is defined the same for each node, typically (lazily)

How the pixel search for DIC works... y-too

x disp (px)	0	+10	+15	+17	+18	+19	+20	+21	+22	+23
y=-5	0.915	0.950	0.975	0.983	0.983	0.980	0.975	0.970	0.965	0.960
y=-4	0.915	0.950	0.978	0.990	0.991	0.987	0.981	0.974	0.968	0.963
y=-3	0.915	0.951	0.980	0.995	0.997	0.993	0.986	0.978	0.971	0.965
y=-2	0.915	0.950	0.979	0.995	**0.998**	0.995	0.988	0.980	0.972	0.966
y=-1	0.914	0.949	0.977	0.991	0.995	0.993	0.987	0.980	0.972	0.966
y=+0	0.914	0.948	0.973	0.984	0.988	0.987	0.983	0.977	0.971	0.965
y=+1	0.913	0.946	0.969	0.977	0.980	0.980	0.977	0.973	0.968	0.963

OK, but subpixel?

Sure, just interpolate your image, and recalculate. Get go far below the pixel



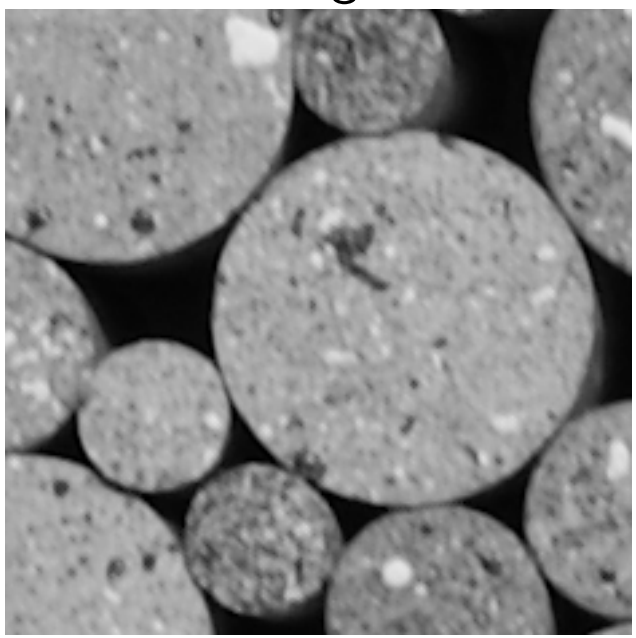
From Dartmouth.edu

The search field can be very big...

Rotation through image interpolation

Correlation Window (Image 1)

Reference Image



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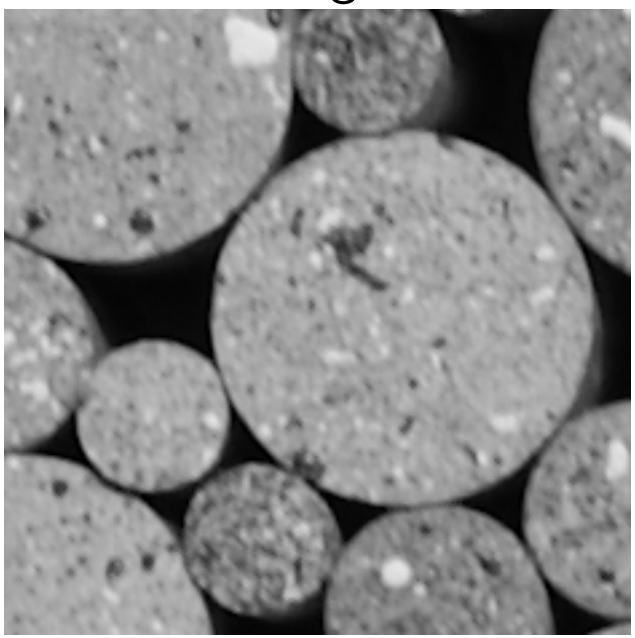
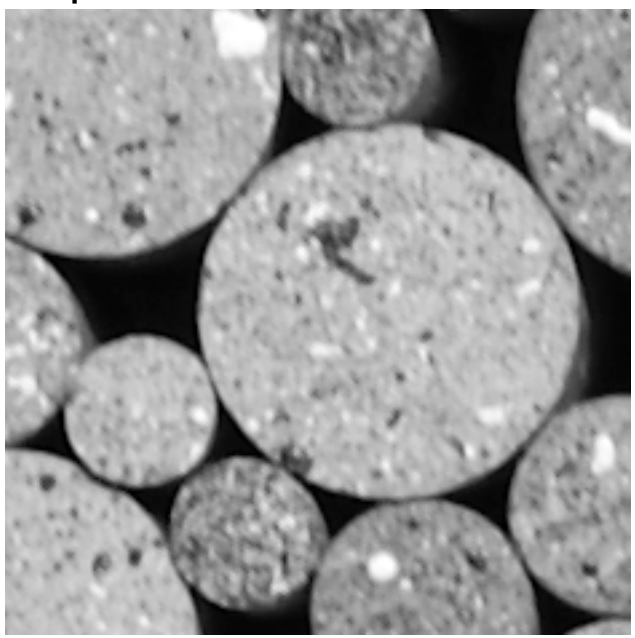


Correlation Window (Image 2)
displacement on table



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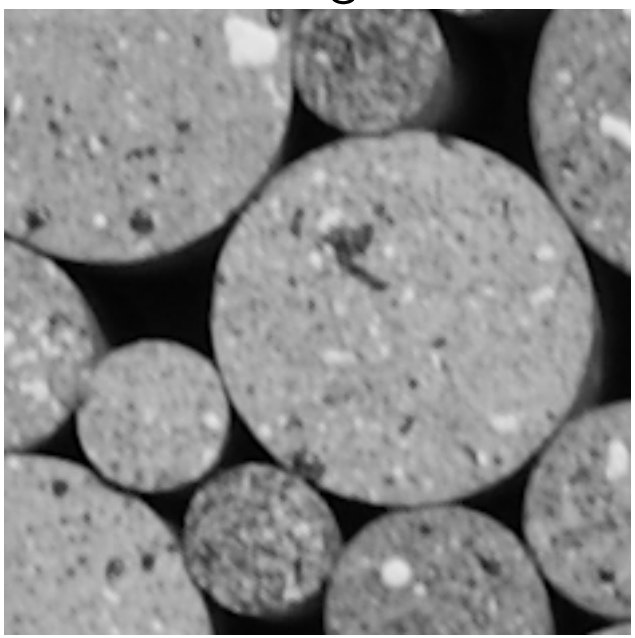

Correlation Window (Image 2)
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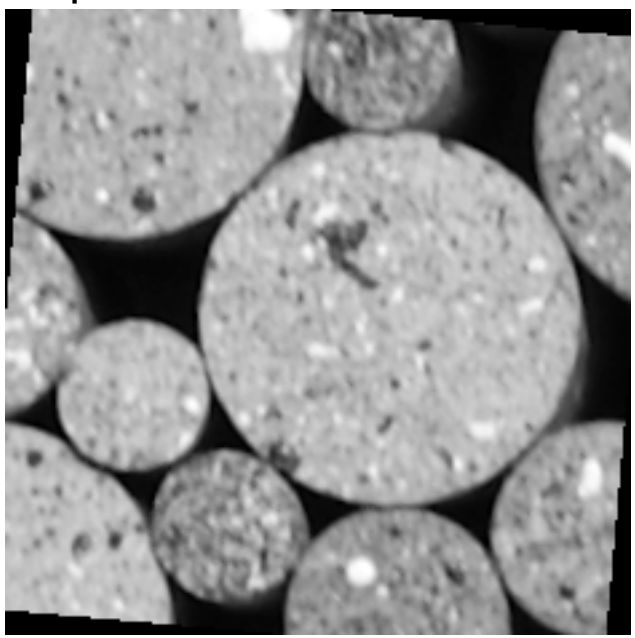

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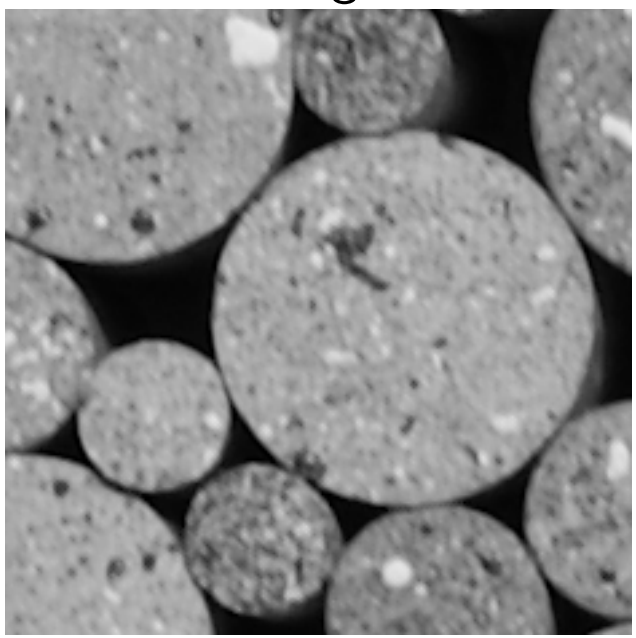
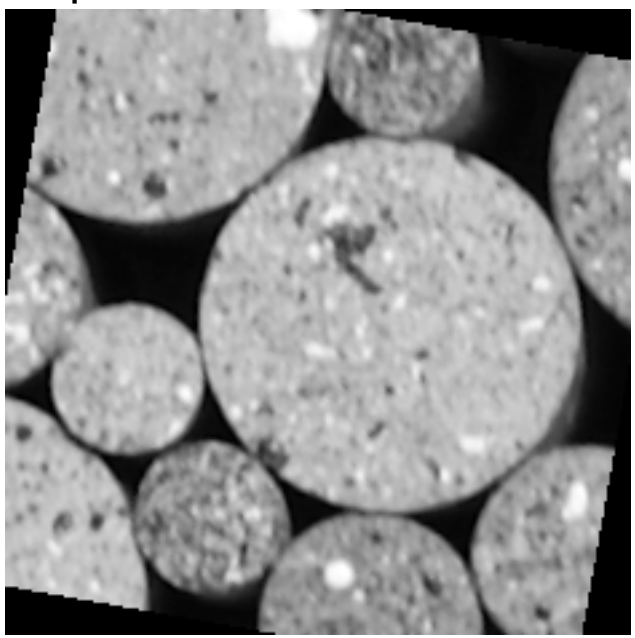
Reference Image



Correlation Window (Image 2)
displacement on table



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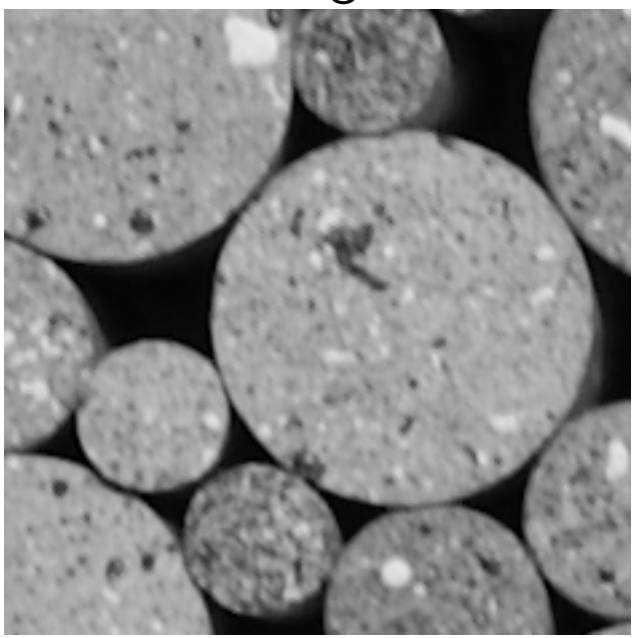

Correlation Window (Image 2)
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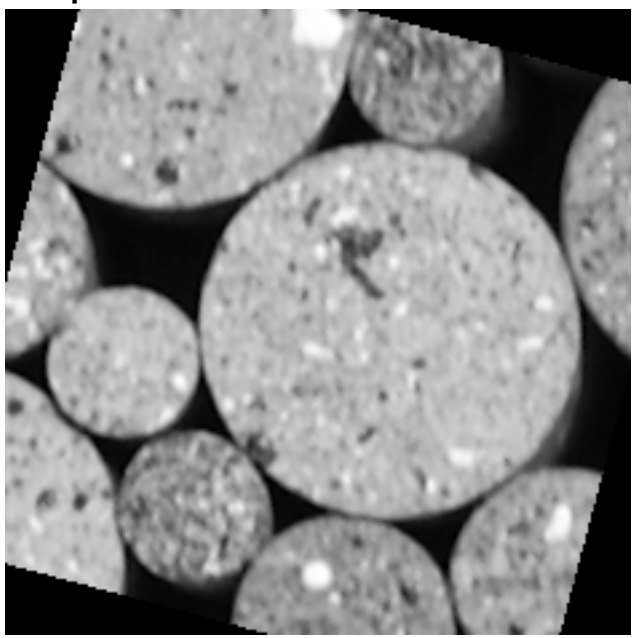
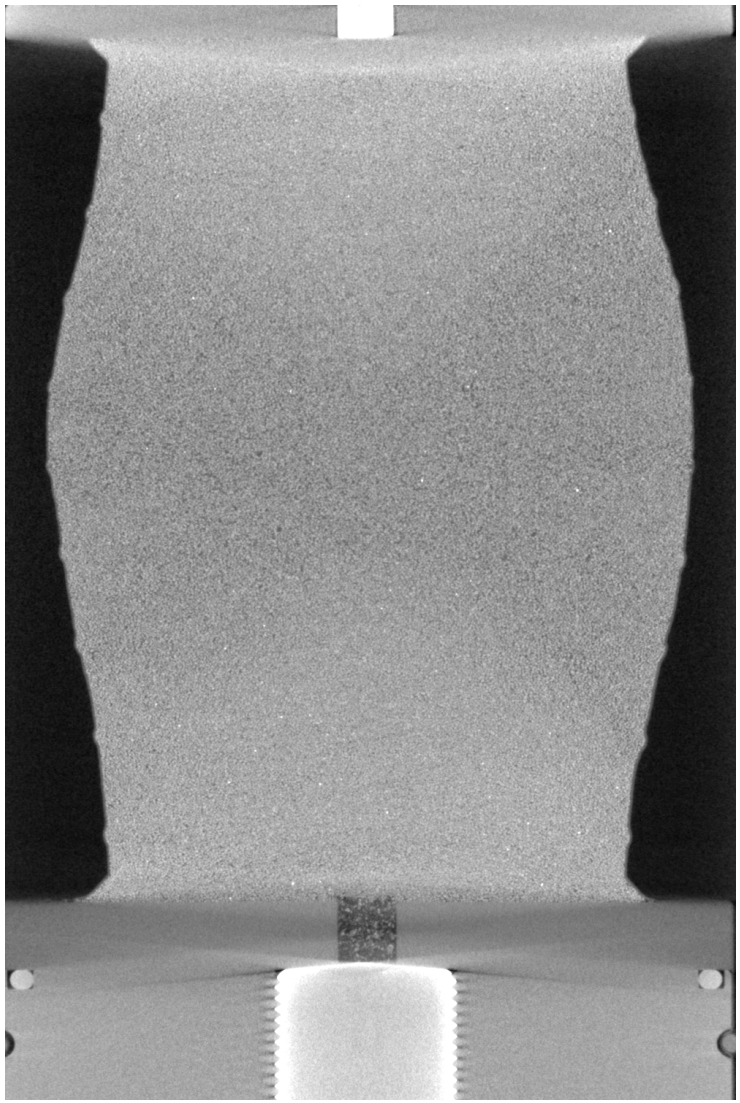


Don't forget

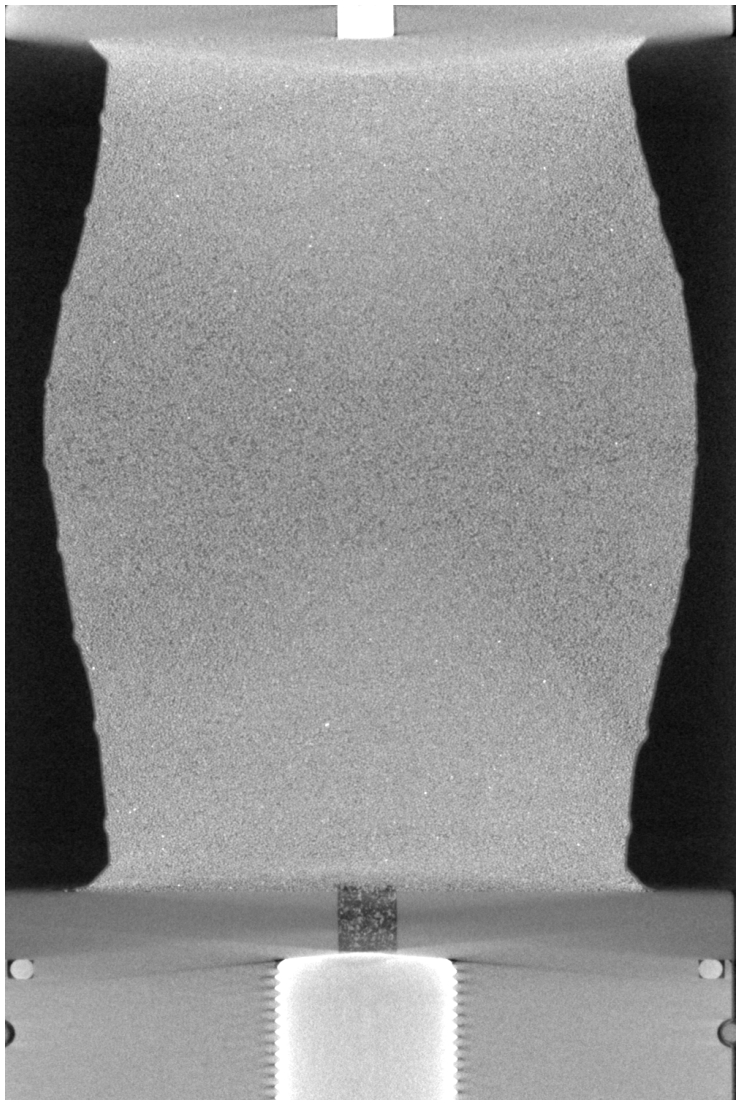
- Respect your data
- Point by point can get lost
- Global can miss some things
- Constraints can be difficult (both in local and global)

Some examples of 4D analysis 1: Point-by-point on complex structure

Step 26



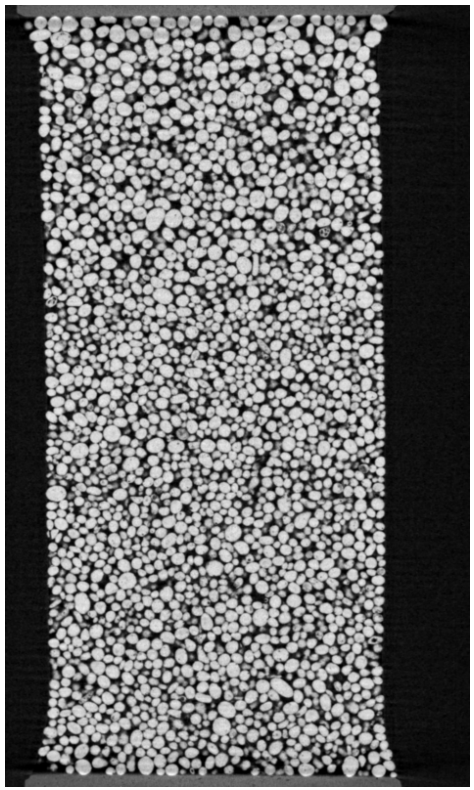
Step 27



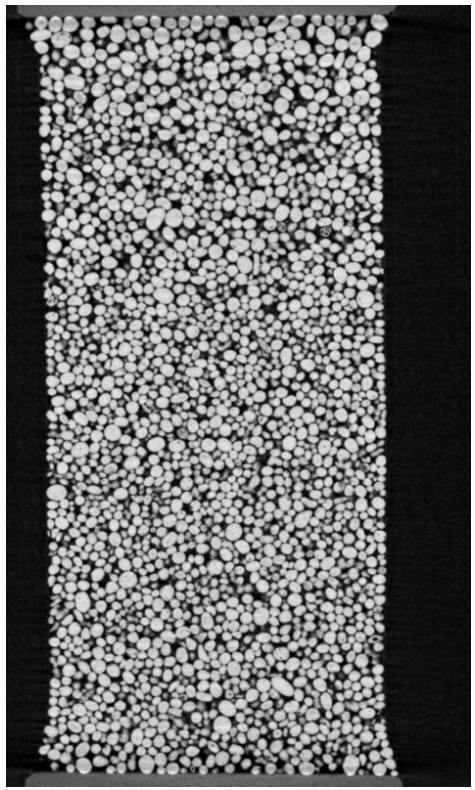
Recent experiments from Jacques Desrues, Laboratoire 3SR, Grenoble

Some examples of 4D analysis 2: subpixel grains

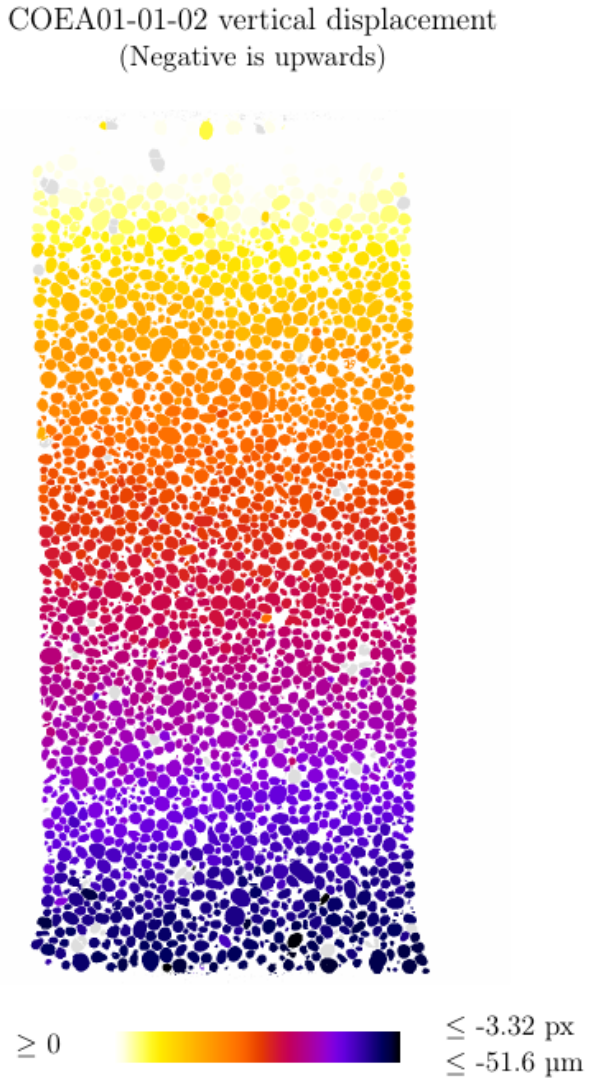
Step 1



Step 2

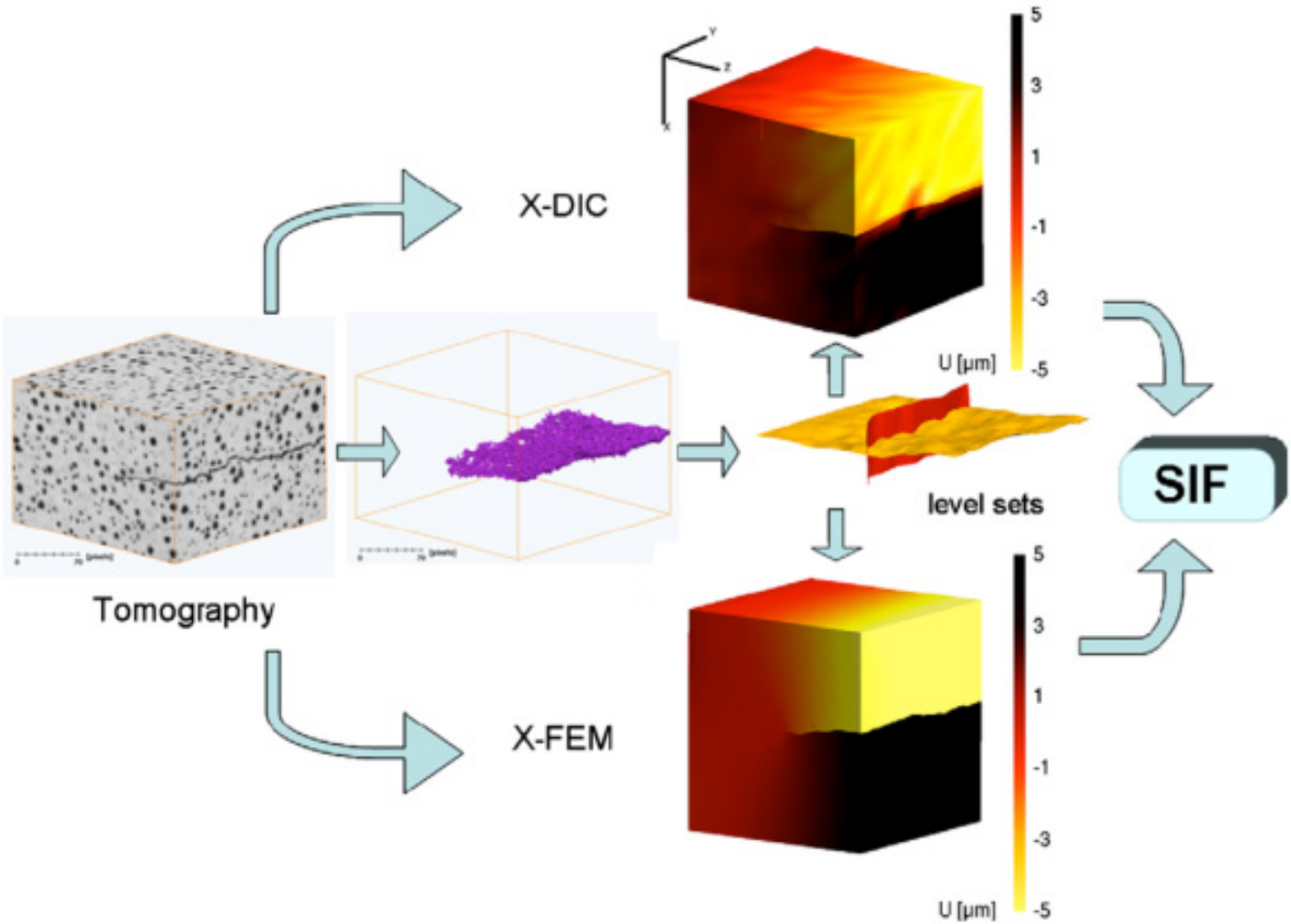


Displacement



Some examples of 4D analysis 3: Global DIC

Image from Cachan



Some examples of 4D analysis 4: Very small clay samples

<videos>

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- Please ask me questions